Ontario Hydro · Research Division · 1983

85-0765/

The cover photo – use of lasers in processes related to nuclear energy

This laser system can be tuned to produce infrared output of optimal frequency for selective dissociation of specific molecules. Its energy could be used, for example, to dissociate molecules that contain atoms of a selected isotope of hydrogen (deuterium or tritium) while leaving most molecules that contain atoms of the other isotopes unaffected.

Deuterium oxide (heavy water) is used as the moderator and the heat-transport medium in the CANDU-PHW nuclear system. Tritium is formed by neutron bombardment during reactor operation, and must be removed periodically to keep concentrations in the heavy water within acceptable limits. Demonstrations of high selectivity in molecular dissociation indicate that a laser technique could serve well as part of a process for isolation of tritium.

Several other potential applications of lasers in processes related to the construction and operation of nuclear reactors are being studied or are being considered for future study. These include the refining of titanium and zirconium, used in alloys for the fabrication of reactors and fuel bundles, the isolation of carbon-14, another radioactive by-product of CANDU operation, and the use of laser holography in recording the physical condition of irradiated (spent) fuel elements.

These studies are directed toward requirements of the construction and operation of CANDU fission reactors. However, continuing development may lead to application of laser processes in the production of fabrication materials (titanium and zirconium) and fuels (deuterium and tritium) for controlled nuclear fusion, perhaps the most promising ultimate energy resource.

Foreword

The Research Division has grown from a small standards and testing section established in 1912 to the organization with a staff of more than 600 supported by comprehensive plant and equipment that meets much of Ontario Hydro's requirement for research and development today.

The work of the Division is varied and challenging. Projects under way support the engineering and operation of a power system that includes hydraulic and fossil-fired generation, a large and still growing proportion of nuclear-fuelled generation, and a transmission and distribution network that serves wholesale and retail customers throughout most of the inhabited part of Ontario. They relate also to the need to help customers to use electricity safely and economically and with good effect as either a supplement to energy from other sources or a replacement for it.

The Division co-operates closely with other parts of the Hydro organization, with other electrical utilities and with manufacturers of equipment and materials. A number of projects are supported by the Canadian Electrical Association, the Electric Power Research Institute in the United States or other organizations, and Ontario Hydro's research and development costs are thus partly offset.

This report outlines some of the work performed in 1983. I take pleasure in presenting it to those who are interested in the Research Division and its contributions to Ontario Hydro and the electrical industry.

F.J. Kee
Director of Research

Contents

The Research Division 3

Major Areas of Research

- Nuclear Generation 4
- Thermal Generation 8
- Alternative Energy Sources 9
- Electric Power Systems 11
- Transmission and Distribution 13
- Energy Utilization and Conservation 17
- Nuclear Waste 20
- Environmental Protection 21
- General Research 23

Resources and Costs 24

Organization 25

Publications and Presentations 26

Frequently used abbreviations

AECL	Atomic Energy of Canada Limited
CEA	Canadian Electrical Association
CSA	Canadian Standards Association
EPRI	Electric Power Research Institute
IEEE	Institute of Electrical and Electronic Engineers
GS	Generating Station
TS	Transformer Station
CANDU-PHW	Canada Deuterium Uranium - Pressurized Heavy Water

Ontario Hydro, established by the provincial Legislature in 1906, is a special statutory corporation with authority to generate, buy and distribute electricity throughout Ontario. Its main responsibility is to provide power to 320 municipalities for distribution to customers in their service areas. In 1983 the Corporation used resources of generated and purchased power with a dependable peak capacity of 25 270 megawatts to produce 106 billion kilowatt-hours of primary energy for distribution to about 3 050 000 ultimate customers.

Ontario Hydro
Research Division
800 Kipling Avenue
Toronto, Ontario
M8Z 5S4

Editing	Brent Blanchard Bob Johnson
Photography	Keith Buck
Design & Layout	Isobel Morgan
Co-ordination	Gary Floyd

Printed in Canada ISSN 0229-6454

The Research Division

The Division

Ontario Hydro not only maintains and operates its power system but also undertakes most of the design and construction necessary to meet growth in demands and to replace old facilities. The system is one of the largest in the world and despite its size and complexity still one of the best in terms of efficiency, economy and reliability in the generation and distribution of electricity. These facts underline the Corporations's continuing success in meeting an engineering challenge that has been made quite formidable by concerns for the environment and for conservation of material and financial resources.

The Research Division plays an important part in meeting this challenge. It provides scientific and technical support for the planning, design and operation of the power system, and carries out investigation and testing that contribute to the solution of day-to-day problems, the development of material and performance specifications and the quality control of purchased materials and equipment.

The pages that follow include brief descriptions of work in progress or recently completed – these indicate the breadth and significance of the Division's research and development program. Information on some of the subjects discussed is available in greater detail in published technical papers or in reports that can be obtained from the address on the opposite page.

Facilities

Most of the Research Division's work is performed in the large complex on Kipling Avenue in western Metropolitan Toronto shown below. The main building, first occupied in 1961, and adjacent facilities for pump testing and high-voltage, high-current, radioactive-materials, atmospheric and biological research provide altogether about 34 750 square metres of office and laboratory space. An outdoor facility at Kleinburg, about 30 kilometres north, provides for the testing of full-scale transmission structures and equipment. Field services are performed wherever required in the province.

Nuclear Generation

Reactor-core metallurgy

A large part of the work of the Metallurgical Research Department relates to programs for evaluation and improvement of the long-term performance of the zirconium-alloy pressure tubes in CANDU nuclear reactors. Projects of this kind have included development of techniques for remote inspection, studies of the effects of temperature, hydrogen content and hydride continuity on fracture toughness, evaluation of susceptibilities to initiation and growth of cracks, studies of irradiation-induced elongation and sag, and investigation of the influences of fabrication processes on metallurgical properties.

The value of these projects was confirmed in August 1983 by requirements created by the rupture of a Zircaloy-2 pressure tube in the reactor of Unit 2 at Pickering GS. The equipment, capabilities and information developed over the years were of substantial help in the examination and analysis of this failure and in determining its relevance to expected performance of other CANDU units.

A different alloy, zirconium – 2.5-weight-per-cent niobium, has been used in the pressure tubes of all CANDU reactors manufactured after units 1 and 2 at Pickering GS. Current research is concerned with the effects of hydrogen content and hydride blisters on the long-term integrity of this material which are expected to be significantly less adverse than with Zircaloy-2. Studies of the deformation of Zr – 2.5-wt-% Nb material under irradiation in the United Kingdom Atomic Energy Authority's DIDO reactor are improving knowledge of factors in various metallurgical fabrication routes that may contribute to slower rates of elongation. Nine tubes representative of three modified fabrication routes under development have been selected for installation and observation in the reactor of Unit 8 at Bruce GS, and the use of tubes manufactured to these metallurgical specifications is being considered for re-tubing Units 1 and 2 at Pickering GS.

Investigation of hydrides and sub-structures in pressure-tube materials by transmission electron microscopy is continuing. High-temperature deformation characteristics are being studied to provide information for use in predicting the effects of hypothetical loss-of-coolant accident conditions.

Remote inspection and evaluation of pressure tubes in CANDU reactors

CIGAR, a Channel Inspection and Gauging Apparatus for Reactors, is now in the final stage of development. The system will provide rapid and accurate measurement of the dimensions and evaluation of the integrity of pressure tubes in the fuel channels of CANDU nuclear units during maintenance shut-downs. CIGAR consists of an inspection head that carries inspection and gauging transducers, a mechanism that drives the head through a defuelled, water-filled pressure tube, remote control of axial and rotational movement of the head, and data acquisition and processing. Part of the system was used late in 1983 to examine pressure tubes in Units 1 and 2 at Pickering GS after the units were shut down subsequent to a tube rupture in Unit 2.

Location of displaced fuel-channel garter springs by eddy currents

In the CANDU reactor, garter or spacer springs are positioned at intervals along the length of the fuel channel to maintain separation between the hot inner pressure tube and its surrounding calandria tube. Occasionally, however, garter springs may be displaced during installation of the channels or during subsequent operation of the reactor, causing tube contact and localized cooling and eventual hydriding of the zirconium-alloy pressure tube.

An eddy current probe has been developed to assist in procedures to locate displaced garter springs and return them to their correct positions. This consists of a bridge-type differential coil which induces eddy currents in the springs while it is being pushed through a pressure tube. A change in probe signal pinpoints the location of each spring. Various models of the probe have been used in operational reactors and in new, uncommissioned reactors at Pickering and Bruce Generating Stations.

Testing of primary-heat-transport pumps

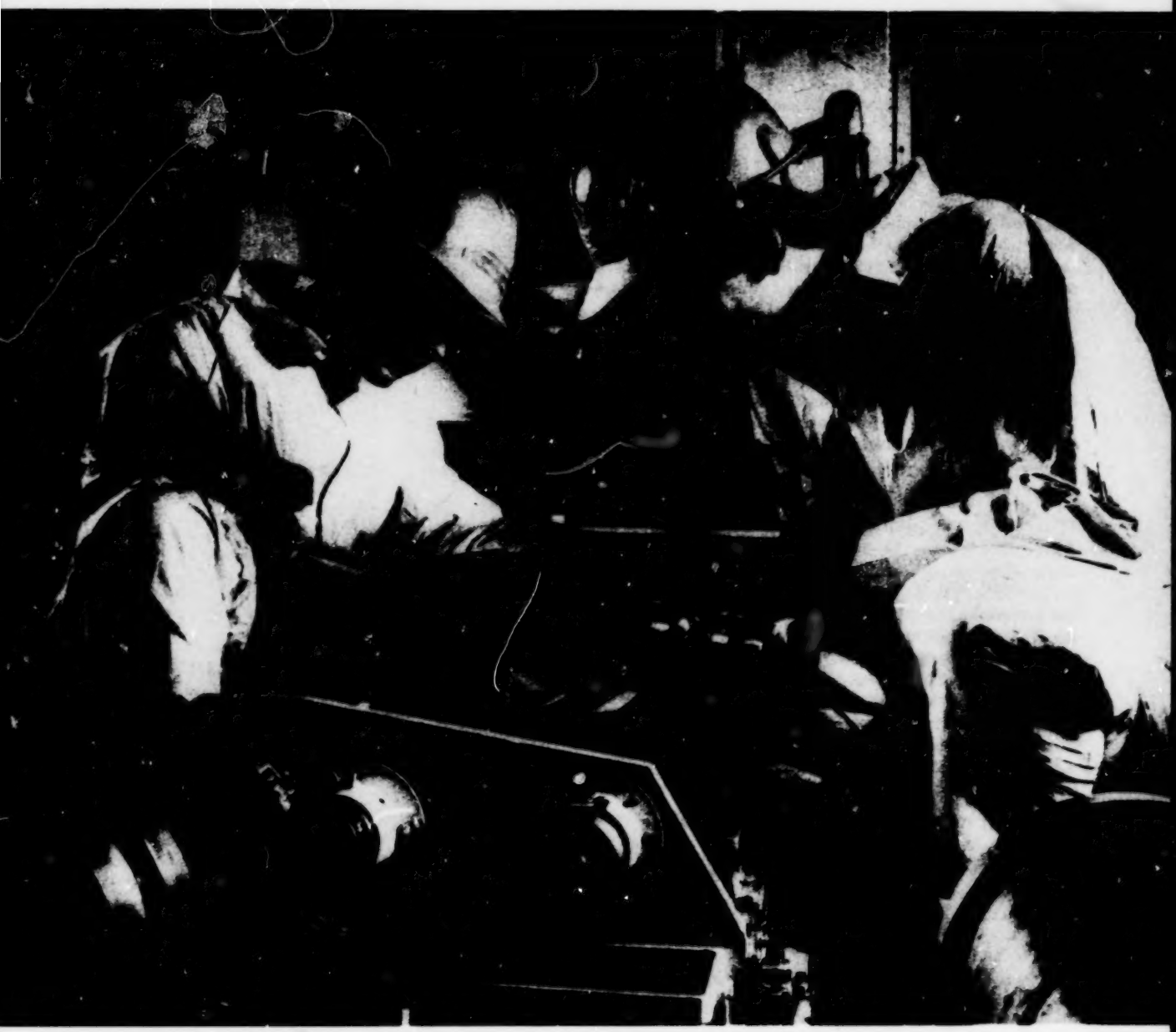
The Research Division's Pump Test Complex was built and commissioned in the late 1970's to provide for comprehensive performance and endurance testing of prototype primary-heat-transport pumps and motors. The program on the Bruce GS machines has contributed to improvements in seal quality and in lubricant selection, start-up and maintenance procedures. In 1983, the test loop was modified and extended to accommodate the Darlington GS machine, for testing in 1984-85.

The Complex, recently renamed The Nuclear Process Components Test Facility, is meeting requirements and finding applications that extend beyond its initial purpose. For example, Bruce and Pickering GS machines were operated under partly-voided, two-phase conditions: they pumped mixtures of steam and water such as could occur with a leak in the primary-heat-transport system. The results demonstrated the ability of the machines to tolerate such rough operation. A similar test is planned for the Darlington pump and motor.

In another application, provision has been made for precise calibration of non-intrusive flow meters installed on a large hot, pressurized pipe of realistic site geometry. These meters will be used in nuclear stations to calibrate and periodically verify in-situ instruments used for the very important boiler feedwater flow measurements.

Thermal-hydraulic studies of two-phase flow in CANDU reactors

Experimental and analytical thermal-hydraulic studies of two-phase flow behaviour in CANDU reactors are in progress. One involves study of two-phase flow in horizontal fuel channels. The experimental data were used to estimate empirical constants in an equation developed for transverse vapour drift, a phenomenon that accounts both for gravity separation, which tends to cause flow stratification, and for



Channel Inspection and Gauging Apparatus for Reactors: *The photo shows parts of the CIGAR drive which will be mounted on the fuelling machine bridge of CANDU reactors. The engineers are checking the inspection head before placing it in a mock-up of a fuel-channel pressure-tube for a test of the system at the Division's Nuclear Process Components Test Facility.*

turbulent diffusion, which tends to homogenize the two-phase mixture. Another involves study of the refilling and rewetting phase of a postulated loss-of-coolant accident. The experimental results are being used to develop constitutive relationships and to verify computer codes. Of particular interest are the effects of flow rate, tube wall thickness, initial tube temperature and water sub-cooling on quenching phenomena.

The studies are supported by development of special instrumentation. One instrument, a gamma densitometer for measurement of average void fractions and flow regime identification in transient two-phase flows, has been tested successfully using air-water flows in small pipes. This new design uses a single gamma beam with a multi-detection system.

On-line monitoring of structural integrity of nuclear power plant components

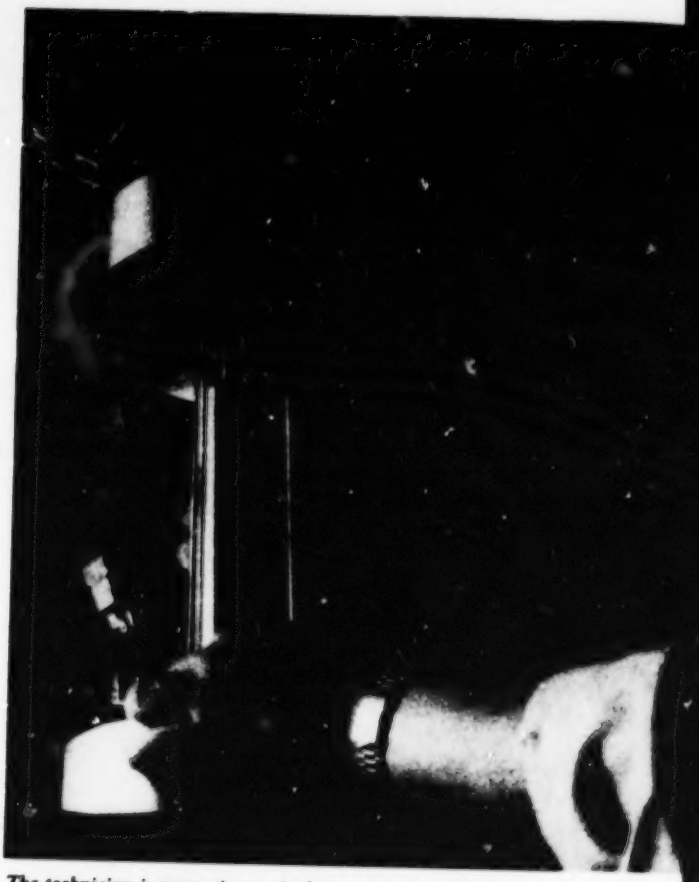
A capability is being developed for on-line monitoring of the structural behaviour and integrity of critical components of nuclear power plants. This is based on direct measurement and surveillance of such structural parameters as strain, stress, temperature, vibration displacement and crack growth. Minicomputer technology is being applied for automatic and continuous analysis of data at the measurement site and for access to the data from remote locations on demand. Information gathered in this way on existing components will be applied in the development of improved equipment for prolonged and reliable use in high-radiation and high-temperature environments.

Vibration monitoring of rotating machinery

A computer-based vibration monitoring system is being developed for monitoring the vibration of rotating machines at Darlington GS, now under construction. The system will automatically perform vibration-signature analyses and produce diagnostic reports. These features are expected to make the new system more effective in detecting and determining the cause of machinery deterioration at an earlier stage than the systems now in use which depend primarily on overall vibration levels. The information provided should reduce maintenance costs and further enhance machinery reliability and safety.

Seismic and environmental qualification of electrical equipment

Seismic qualification of a variety of electrical components has been performed for some years to ensure compliance with requirements governing their use in nuclear power plants. The components include motor control centres, relay panels and cable trays. Seismic and environmental qualification of batteries was initiated in 1983. Most qualifications are achieved through application of combined analytical and experimental techniques. Special efforts are made to demonstrate adequacy of components while retaining their flexibilities and low natural frequencies. This



The technician is preparing a rig for use in an autoclave experiment to study corrosion under sludge in nuclear steam-generators.

is particularly applicable to panels and cable trays already built and installed.

Decontamination of nuclear heat transport systems

A major program was undertaken to develop a chemical decontamination process to reduce radiation fields around the heat-transport systems of nuclear reactors, particularly components near the reactor face. This will facilitate work on the large-scale replacement of fuel channels that will soon be under way in Units 1 and 2 at Pickering GS.

As part of the CANDECON development program, the structure and composition of the oxide on pipe surfaces is being determined. Also, the ability of the regenerable CANDECON chemical reagent to hold the dissolved species in solution is being studied electrochemically and under test conditions representative of those found in the heat transport system. Related studies include specification of a chemical hot conditioning process that would generate a protective oxide coating on heat-transport-system surfaces prior to initial reactor start-up.

Steam-generator corrosion

Work is continuing on research to define the conditions under which corrosion may occur in the steam generators of CANDU units and on the development of means to control these conditions and so maintain optimum serviceability and effectiveness.

The corrosion of steam-generator materials in regions of restricted flow is being investigated in situ and at the laboratory. Probes that simulate regions of contact between steam-generator tubes and support plates and tubesheets have been used in autoclave experiments to study the concentration of feedwater contaminants in crevices and under sludge deposits, and to determine the nature and severity of corrosion in these places. Rapid corrosion of carbon steel and pitting of tube alloys have been observed, and the effects of contaminant concentrations, temperature and sludge characteristics are being investigated. In-plant autoclaves are being used to monitor tube scaling and corrosion in steam-generator blowdown water.

A model boiler test-loop has been assembled for use in evaluating the effectiveness of various chemical additives in minimizing the formation of corrosion products in the feedwater system. This will provide information that will be useful in assessment of operating practices and design of feedwater systems. A chemical cleaning solvent suitable for descaling the secondary side of a nuclear steam generator has been developed and used successfully in cleaning the steam generator of the Nuclear Power Demonstration unit at Rolphton, Ontario. Work is now under way on the development and testing of improved agents for dissolving the thick, hard, copper- and iron-containing sludge piles that are accumulating at junctures between steam-generator tubes and tubesheets at Bruce GS.

Crevice corrosion of moderator heat-exchanger tubing

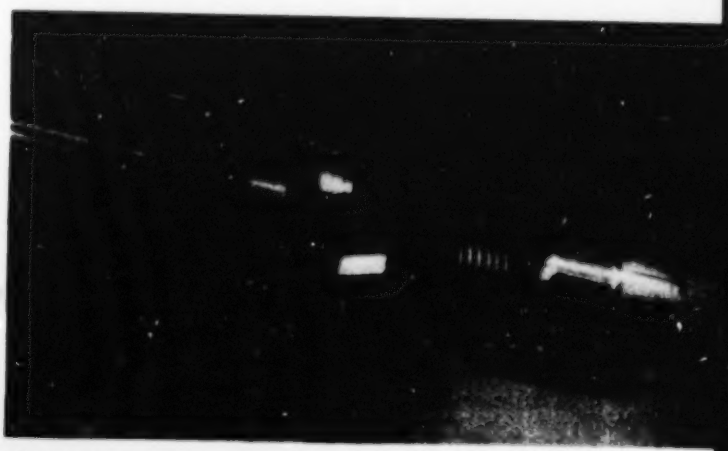
Possible solutions to the problem of crevice corrosion of Incoloy 800 moderator heat-exchanger tubing are being evaluated. In preliminary work, electrochemical polarization tests were performed on I800 in samples of water from Lake Ontario at Pickering GS and from Lake Huron at Bruce GS, and in several specific solutions. The results indicate that, in the absence of clayey silt, I800 is much more resistant to attack in Bruce GS water than in Pickering GS water. At ambient temperature, I800 is very resistant to damage in Pickering water, but at slightly elevated temperatures, above 40°C, crevice attack is more readily supported. The presence of clay increases susceptibility at lower temperatures, so that crevice attack can be supported at 30°C. This suggests that chemical cleaning of moderator heat exchangers may be beneficial in reducing the likelihood and extent of tubing crevice corrosion.

Biofouling of heat exchangers and condensers

A study was initiated to evaluate the role of micro-organisms in the biofouling and corrosion of the cooling-water side of heat exchangers and condensers, and to develop early-detection methods and effective control strategies. Probable incidents of biofouling-related corrosion and the consequent loss of heat transfer efficiency were investigated at some generating stations. Selective attachment of microbes to metal surfaces has been shown to depend on cell morphology and available numbers. Examination of biofouling rates of materials commonly used in heat exchangers and condensers indicated that stainless steel is the most susceptible material, followed by a titanium alloy and admiralty brass.

Behaviour of reboilers in heavy water plant

In a study initiated by the Nuclear Generation Division, the boiling and two-phase flow characteristics of a simulated steam reboiler are being investigated to update and verify models and correlations used in computer simulations of heavy water plant operation. Tests involve boiling of different fluids around heated tube bundles in various geometries. Parameters of interest are local heat transfer coefficients, void distribution, pool swell and collapse, and critical heat flux.



The Division's electromagnetic laboratory has developed a number of techniques for remotely controlled manipulation of metal parts in areas of difficult or dangerous access. The coil in the photo is used in a fast-induction heating technique to separate the calandria tubes of a nuclear reactor from their rolled joints in the calandria tubesheet. Similar coils are used to separate pressure tubes from their end fittings as part of the large-scale fuel-channed replacement program.

Thermal Generation

Residual creep life of steam lines and headers in fossil-fired steam generators

A CEA-funded project to investigate the residual lives of steam-generator components was completed in 1983. The results indicate that components that operate under design conditions, such as main steam lines, should have a service life of about 200 000 hours. However, in places where temperatures may exceed design levels, superheater and reheater outlet headers for example, creep failures could occur in a shorter time. The report proposes a plant monitoring procedure to log data for component life assessment, and recommends further research work to refine prediction techniques.

Coal cleaning by oil agglomeration

Chemical Research has developed and demonstrated a process that uses oil agglomeration to clean coals to very low ash levels. Coals were tested on the bench scale at the National Research Council in Ottawa to identify requirements for pre-treatment processing, and the more promising coals were then re-evaluated in Ontario Hydro's 500-kg/h pilot coal-cleaning plant.

The study included development of a technique which recovers for re-use more than 95 per cent of the oil used in agglomeration, substantially improving the economy of the process. A conceptual design for a 100-mg/h plant that incorporates this technique was prepared and evaluated for economic feasibility.

The project was funded jointly by Ontario Hydro and EPRI. The process could provide suitable coal at economic cost to replace oil for firing Lennox GS when the station is again required for power production.

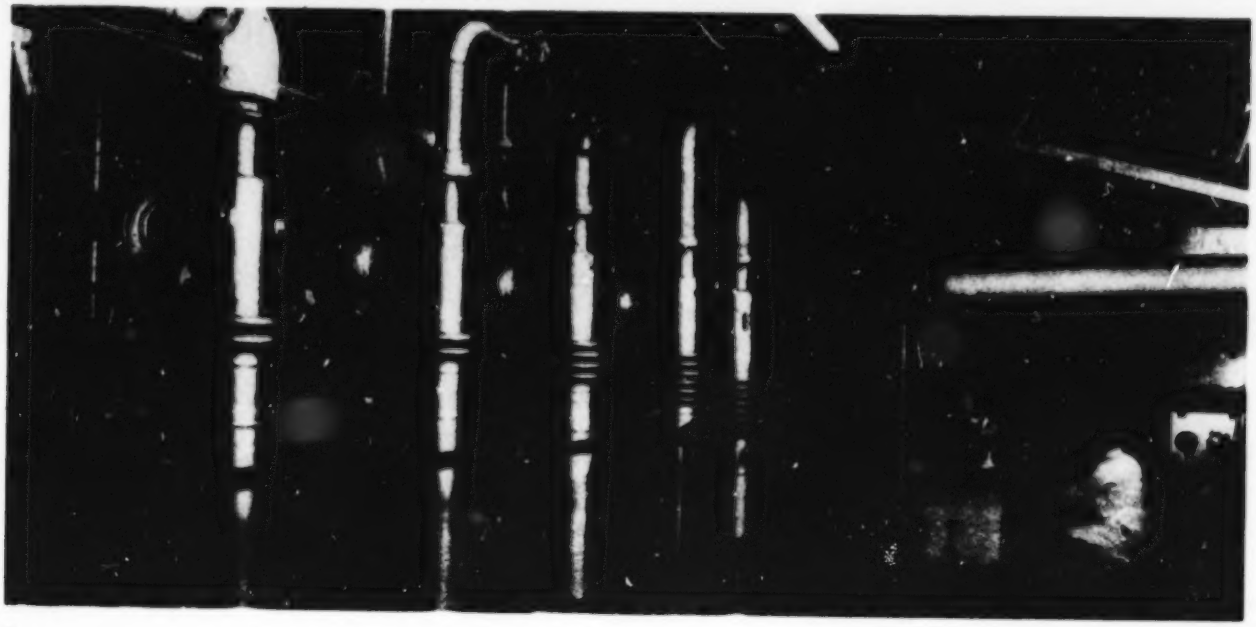
Disposal and utilization of coal ash

Coal burning generating stations produce large volumes of ash. Research and testing have been undertaken to turn this substance, particularly fly ash, into a profitable by-product rather than a costly waste, and uses have been found for fly ash in the ready-mix concrete and cement industry and in highway construction. As a result coal ash is now being recognized as a valuable resource in the construction industry.

Disposal: In 1983 the Research Division was involved in studies to extend the life of the Nanticoke GS disposal lagoon; ash dykes, constructed from dredged lagoon ash, are a significant feature of the new ash handling system. The progress and sequencing of a large structural landfill program in Mississauga was monitored. A CEA contract to model ash leachate plume development was obtained; long-term column tests were continued to evaluate release of arsenic and selenium trace components.

Utilization: Frost heave and structural properties of bottom ash were compared with standard road-base fill materials. Feasibility work was done on replacement of cement in mine backfill, emphasizing use of lignite fly ash. A major overpass was built in Sarnia. Resistance of concrete to sulphate attack and alkali reactivity was improved by the use of fly ash in the mix. A long-term study of metal corrosion in fly ash was continued.

The Division's Combustion Research Facility is used in determining the characteristics of coals and other fuels for thermal-electric stations. Parts of the heat-exchangers and the top of the combustion chamber can be seen in the photograph.



Alternative Energy Sources

Tritium and nuclear fusion

Nuclear fusion uses deuterium and tritium, the heavy isotopes of hydrogen, as fuel and offers the world access to an energy source which in ultimate development may be virtually free of fuelling contraints. The process is of particular interest in Ontario because of the expertise developed by Ontario Hydro, AECL and other organizations in the production of heavy water (D_2O) and in the processing and handling of tritium, which is a radioactive by-product of the CANDU reactor.

Uranium getter beds may be used in the primary delivery systems for fusion reactors and also as temporary storage and purification beds in Ontario Hydro's Tritium Application Program. The performance characteristics of uranium beds were investigated in two interrelated experimental programs. An assessment of factors that influence hydrogen loading rates was carried out on a 15-gram bed designed and built by the Research Division. The impact of scaling up to a 6-kg bed and the importance of double containment were evaluated using the uranium bed designed and built by the Los Alamos Scientific Laboratory. A 3-kg bed that uses double containment was designed on this basis and is expected to be ready for hydriding tests in 1984.

In a fusion fuel clean-up system, impurities will be removed from the fusion reactor exhaust and the neutral beamline in order to recover pure tritium. One method of recovering tritium uses uranium hot metal beds to reduce tritiated water to elemental forms. However, studies have shown that the catalyzed water-gas shift reaction is a better method of reduction. Catalytic reactors were built and tested under various conditions and a full-scale prototype has been designed to meet the Tritium Systems Test Assembly requirements.

Molecular seives are being studied to determine the feasibility of using microwave drying for their regeneration and also to establish their performance at water vapour concentrations of 10 to 1000 $\mu\ell^{-1}$.

Another study has shown that helium-3, which is obtained from decay of stored tritium, can be activated in the neutron flux of a CANDU reactor and thus enhance production of tritium by the unit. Helium-3 can therefore be a valuable resource for production of tritium to serve the emerging market for fusion fuels.

Grouting techniques

Attempts to use conventional cement grout to seal fractures in the rock foundations of generating stations to have often been frustrated by the rapid flow of water through the fractures. The Research Division has studied other grouting materials and techniques for use in these difficult situations, and has developed a method for effective repair of these fractures. This involves use of an asphaltic grout to reduce the water flow sufficiently to permit effective application of

The Concrete Technology Section of Civil Research uses automated freeze-thaw cycling equipment in evaluating the durability of concrete made with aggregates, cements and admixtures from various sources.

a permanent cement-type grout The method was used successfully at Stewartville GS.

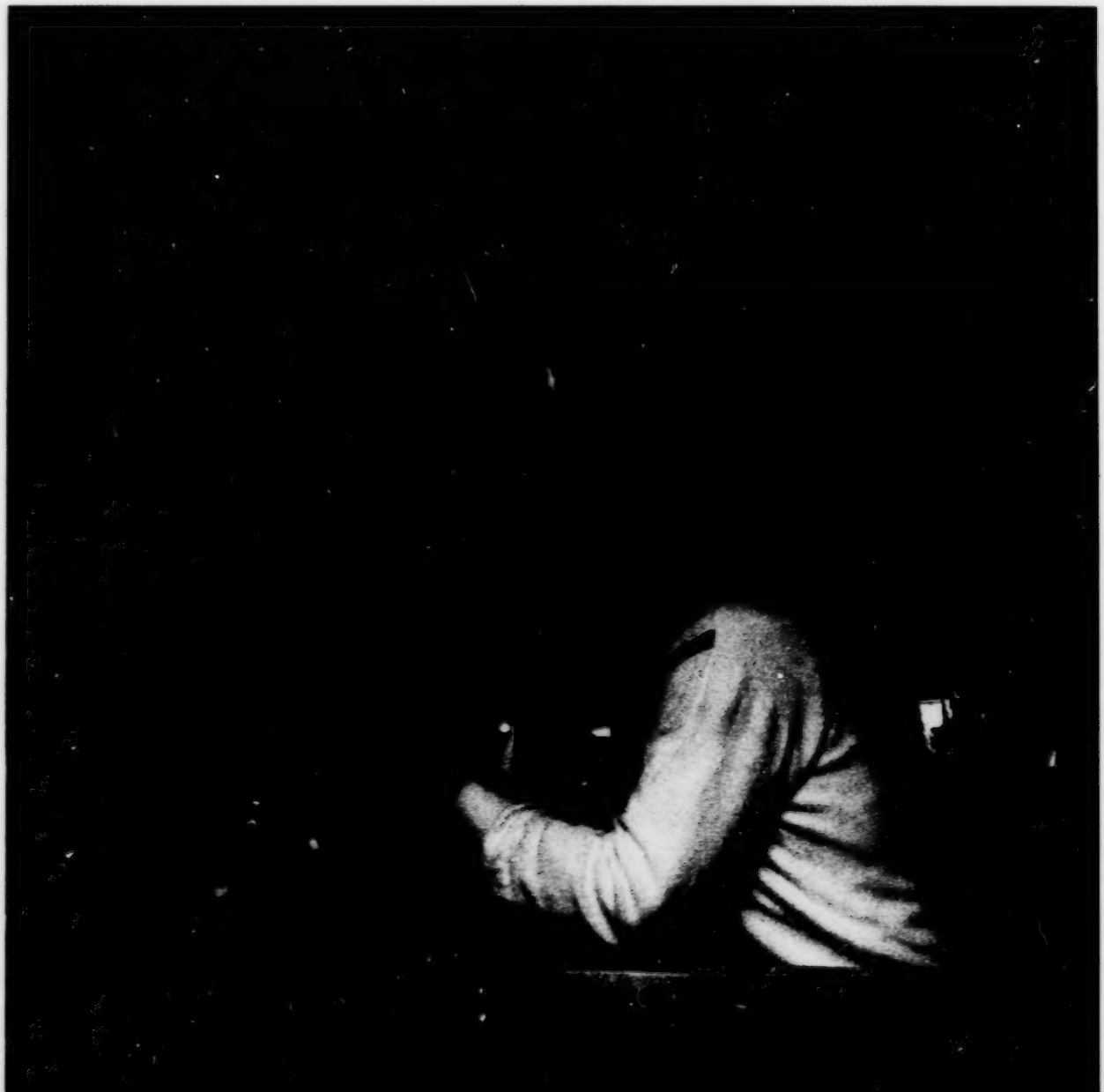
Stress measurements in rock

The powerhouse of the New Brunswick Electric Power Commission's Mactaquac GS has suffered structural distress during the past few years. Research Division personnel have made a series of stress measurements in various parts of the dam structure and in the underlying foundation rock and this has provided some clues to the cause of the problem. An extensive instrumentation system to monitor the powerhouse structure on a long-term basis has been installed in order confirm the preliminary findings.

Polymer batteries

A program is under way to develop lightweight storage batteries that would use conducting polymers as the active electrode materials. The results show promise for development of batteries of this kind and for their use in applications such as electric utility load-levelling and electric vehicles.

Transient-pressure testing of rock: *The hydrogeology engineer at the impromptu desk and his workmate on the scaffold are trying out a newly developed technique for determining the effects of excavation and construction on the integrity of rock — in this case beneath the concrete lining of the cooling-water-intake tunnel at Darlington GS.*



Electric Power Systems

Modelling of steam-turbine generators

Parameters for modelling synchronous generators have usually been obtained in the past from sudden short-circuit tests made by the manufacturer in accordance with conditions in the IEEE test code. However, it became apparent several years ago that the information obtained in this way is not fully satisfactory for either computation of transient stability or the design of power system stabilizers.

To obtain more useful information, Ontario Hydro began to make its own frequency response tests on all new machines. Trials of tests made with the unit running and with it shut down led to selection of the latter as the best method for obtaining modelling data. Standstill frequency response tests provide the most complete data, can be performed in the factory and are not a hazard to either the generator or the security of the power system.

The IEEE has incorporated the standstill frequency response test as a trial method in a new edition of the test code. If the industry reaction remains favourable, the method will become a standard and new machines will be delivered complete with models derived from standstill frequency response tests made by the manufacturer.

Effects of electric power lines on radio broadcasting

Location of a major electric power line close to an AM radio broadcast transmitter can be a disadvantage to the broadcaster as the steel towers may pick up the radio signal and retransmit it in other than the required direction. Ontario Hydro is therefore co-operating with radio broadcasters, CEA and other Canadian research organizations in a major investigation of radio broadcast reradiation. The work is aimed at developing methods for accurately predicting reradiation and devising measures to minimize its adverse effects.

Extensive field measurements have been made on a 500-kV double-circuit power line under construction. A portable radio transmitter was used as a signal source, and the resulting radio-frequency currents in the towers and overhead ground wires were measured. Various devices were attached to the towers and ground wires and investigated for effectiveness in impeding the flow of radio-frequency currents and thus minimizing reradiation. In some cases, where the power line is close to two radio broadcast transmitters, it is necessary to present a high impedance at the frequencies of both stations.

One such attachment consists of an insulated wire parallel to the upper part of each tower leg and pulled out at an angle from the lower part. By means of capacitors at ground level, these devices can be tuned to decrease reradiation at two different frequencies simultaneously.

Electrical Research Department staff discuss modification of circuit-board layout for the microprocessor-based OH180 programmable controller.

Electric Power Systems

New electronic developments improve power system efficiency, economy and integrity

The Research Division has co-operated with the Design and Development Division in development of the OH180, a microprocessor-based programmable controller that will be used instead of conventional relay logic control systems at Darlington GS. The design is such that one standard controller, when used in conjunction with a specially programmed plug-in logic module, will perform the control logic for any of the many different controller applications at the nuclear station.

Each OH180 controller has a separate dc-dc converter to supply isolated power to the station control wiring associated with it. This prevents faults on one control system from affecting other systems, and makes it practical for each controller to include means for determining the occurrence and location of grounds on station wiring. Other features include monitoring of the continuity of associated station wiring, and a diagnostic system that permits the unit to monitor its own operation. All input and output circuitry has been designed to withstand Level B (2500 volts) of Ontario Hydro's standard high-voltage transient immunity test.

Production of 2000 OH180 programmable controllers for Darlington GS is now under way.

The TCX transformer controller, which initiates tap changes to regulate transformer secondary voltage, was developed and introduced about two years ago as one of the first applications of microprocessors in the field of protection and control. This is now in wide use on the Ontario Hydro system. It provides a tap changer controller that is more accurate, more flexible, smaller and less costly than commercially available devices based on conventional technology.

The HTDX1 timing relay has been developed to cover all the common ranges of timing values and supply voltages that previously could be met only by a large variety of timing relays. The new relay can operate on 250-V, 125-V or 48-V dc systems and the delay can be adjusted from 30 ms to 99 s. Digital timing logic is used with a crystal-controlled oscillator to provide accurate and repeatable operating times. Field tests on several relays have been completed, and the HTDX1 will now be used in relay protection standards prepared by the Design and Development Division. The cost will be about half of that for comparable products now commercially available.

The SCX synchrocheck relay prevents damage to a generator that might be caused by connecting the machine to the power system before it has been correctly synchronized. The relay measures the differences between voltages, frequencies and phase angles on the system and in the generator and then compares these with selectable limits to determine if the unit is matched closely enough to the system to be put on-line. The relay provides self-testing, simple installation and fast response, and requires no calibration. At present, 50 relays are being produced for installation on large thermal and nuclear generating units throughout the Ontario Hydro system.

Diagnostic testing of generator insulation in steam-turbine units

In recent years, a partial discharge analyzer has been developed for diagnostic testing of the insulation of hydraulic generators without need for service interruption. This instrument is now widely used in routine maintenance programs at hydraulic generating stations of Ontario Hydro and other utilities across Canada, and has resulted in significant savings in operating costs through reduced generator downtime and improved maintenance scheduling.

As Ontario Hydro's thermal generating units age, the need for a similar test procedure for diagnosis of the condition of insulation in steam-turbine generators has become apparent. For physical reasons, however, installation of the necessary coupling devices in these machines is not practicable. An alternative method involving installation of "directional" couplers on external buswork of steam-turbine generators has therefore been proposed. Under CEA sponsorship, preliminary studies and field tests are in progress to verify the concept and facilitate extension of partial discharge analysis to steam-turbine generators.

System reliability studies

A probability method and computer program have been developed for application in the operational planning of the generation system. The expected energy shortfall is used as a risk index for determining the adequacy of the available generating capacity to supply the forecast system load.

Standby combustion turbine units

The availability of a standby combustion turbine unit under emergency conditions must be tested at regular intervals. Methods have been developed for determining the optimal interval between two consecutive tests for this purpose. Methods have also been developed for assessing the reliability of a system of several standby combustion turbine units in a nuclear generating station with consideration given to the trade-offs between the number of standby units and the ability to repair more than one failed unit at the same time.

Transmission and Distribution

Improved control of conductor vibration

Wind-induced vibration of transmission-line conductors is a widespread and costly phenomenon. Vibration dampers now in use have less than optimal effect; to avoid failures from vibration fatigue, conductors are usually strung at tensions of only 20 per cent of rated tensile strength (RTS).

However, experimental verification of analytical models of vibrating single and bundle conductors with dampers and spacer dampers is nearing completion and the models are being used in development of improved dampers and damping strategies. Dampers of more promising designs are tested also under natural conditions on a full-scale test line at Kleinberg.

Development of more effective dampers will permit stringing of conductors at tensions as high as 40 per cent of RTS. This will make it possible to uprate the ampacity of existing lines and to build new lines on shorter or more widely spaced towers, thus reducing costs and improving aesthetic affects.

Wind and ice loads on conductors and transmission tower design

In 1975, because of concern about assessment of weather-related loads and possibly inappropriate effects on transmission-tower designs and costs, Ontario Hydro initiated a program to monitor the response of transmission lines to wind and ice loading. Since then a comprehensive instrumentation system has been developed which measures and records air temperature, wind speed and direction, wind and ice loads on conductors, insulator swing angles, dynamic loads caused by conductor galloping, and selected structural responses.

Analysis of data obtained in a wide range of weather conditions by systems installed on three 230-kV lines and one 500-kV line indicate that current design specifications may provide transmission-tower structures that are stronger than necessary. Gathering and analysis of data are continuing and are expected to result in more appropriate assessment of weather-related loads and perhaps lead to significant savings in capital costs for towers.

In a related study, a method is being developed for predicting extreme design wind-speeds from records for relatively short terms (three to five years, for example) for use in design of transmission lines at locations where weather records for longer terms are not available. At present the method is being checked for accuracy by comparing predictions based on short-term data with actual extremes for weather stations where long-term records are available.

Galloping of distribution-line conductors

Ontario Hydro began studies of distribution-line galloping several years ago as an extension of field-trial research of promising galloping control devices on transmission lines.

The technician is installing detuning pendulums on a four-conductor-bundle span at the Kleinburg transmission-line test station.

Allowances for galloping of conductors under the effects of icing and wind substantially increase capital costs for transmission lines, and the effects of galloping increase maintenance and operating costs. However, conclusions based on a large number of observations of a range of single-conductor lines at test sites in Canada and the United States indicate that properly applied detuning pendulums will reduce galloping amplitudes to 25 per cent or less of a calculated theoretical maximum.

Several test sites have been established on distribution lines in southern Ontario to observe the effectiveness of some of these devices.

A new CEA project addresses the problems of galloping on distribution lines across Canada. The main objectives are to determine the extent of distribution-line galloping problems, to expose promising galloping control devices to a wide range of Canadian weather, to obtain reliable observations of the control devices during galloping occurrences, to determine the overall effectiveness of control devices, and to provide recommendations on the application of these devices to eliminate or reduce the effects of galloping on existing and new distribution lines.

A survey of Canadian utilities has indicated wide interest in control of distribution-line galloping; the annual cost of the galloping is estimated at $400,000.

Transmission lines and farm safety

Operation of a transmission line is inevitably accompanied by imaginable and possibly hazardous situations associated with faults or equipment breakdowns. There are particular concerns about the safety aspects of possible electrical effects on farming operations. Several different modes of coupling between overhead conductors and farm machinery and irrigation hardware can result in high step and touch potentials that are accessible to farm workers and the general public. To alleviate these concerns, theoretical studies, field tests and demonstrations have been conducted and these have shown that transmission-line operation and safe modern farm practice are compatible.

Transmission and Distribution

Compressive loading in ACSR

A recently developed computer program for Sag-Tension Evaluation by Strain Summation (STESS) models the sag-tension behaviour of steel-reinforced aluminum conductor (ACSR) with high accuracy. The program determines the cumulative effects of loading conditions and takes into account the compressive loading of the aluminum component that occurs at high temperatures because of the relatively high thermal expansion of aluminum. This augments tension in the steel core and increases sag.

The ability of the full aluminum component to support a compressive load is demonstrated by the extreme form of birdcaging shown in the photograph. This occurred when the outer layers of aluminum strands were removed after a test that had strained the aluminum but not the steel core beyond the elastic limit. The birdcaging was accompanied by shortening of the conductor and decrease in sag.

Release of compressive loading in ACSR

Reliability and maintainability of gas-insulated substations

Gas-insulated substations (GIS) incorporate a relatively new technology that has had quite extensive application at lower voltage classes in Europe – insulation of buswork and switchgear by compressed sulphur hexafluoride (SF_6) gas in grounded enclosures. This permits construction of stations that require only a small part of the land area needed for stations of conventional design. Environmental and aesthetic concerns and rising land costs have led to installation of increasing numbers of GIS on power systems in North America.

However, with extension of the technology into higher voltage ranges, the reliability and maintainability of GIS have fallen short of expectations, resulting in lengthy and costly outages. Ontario Hydro has therefore initiated a broad program of research to improve the performance of GIS. This program makes use of a small 138-kV research GIS, erected from parts that had been intended for Toronto-Central TS, which was cancelled because a suitable site could not be obtained. It includes study of the reliability of GIS disconnectors and of the transient overvoltages created by their operation, development of improved test techniques to ensure reliable operation under a wide range of conditions, preparation of guidelines for dealing with electromagnetic interference in auxiliary and control wiring, and development of procedures for safe cleanup and maintenance after failure of GIS components.

The GIS reliability research program has attracted interest and support from CEA in Canada and EPRI in the United States and also from individual utilities in North America and overseas. Several manufacturers of GIS components have been involved – one sent a researcher to work at Ontario Hydro for over a year.

Probabilistic design of high-voltage transformer stations

Excessive mechanical tensions caused by high fault currents sometimes break insulator strings in high-voltage transformer stations. The fault current and the ability of insulators to withstand the applied stresses are both random quantities with associated probability distributions. Conventional (deterministic) techniques used in the design and uprating of transformer stations usually assume worst-case values of variables and parameters of interest – the highest possible applied stress and a low value for insulator strength. This usually leads to results that provide negligible risk of failure but very high design and uprating costs.

In a study now in progress to determine the future uprating needs of Middleport TS for the year 2000, a probabilistic approach is being adopted which enables more realistic values of the design parameters to be obtained with the same degree of confidence. A computerized scheme with six stages has been developed for the purpose. The goal is to calculate the probability of mechanical failure of string insulators in various bays of the station and to evaluate the associated risks to personnel and equipment.

Thermal analysis and sensitivity evaluation of power cables

Design and operation of underground power cables require accurate evaluation of cable temperature and the associated current carrying capability. As part of a CEA sponsored project, efficient and accurate finite-element techniques have been developed to calculate the cable temperature and ampacity. Advanced, sparsity-based finite-element programs have been developed for steady-state and transient analysis of power cables in thermal backfill, in duct bank, or direct-buried. The programs employ newly developed algorithms to calculate the sensitivity of cable ampacity to variations in soil, ambient and boundary parameters. Using these automatically evaluated sensitivities, the cable designer or operator can assess the effects of environmental variations in a fast, direct manner.

The thermal model and software have been tested and verified by experiments in the soils laboratory. The theoretical and analytical developments and the associated

***Research TS:** This 138-kV, SF_6-insulated substation is being used by the Research Division in an experimental program concerned with the reliability and maintainability of gas-insulated substations.*

software are being extended to include soil moisture migration in the thermal model and to evaluate the associated ampacity sensitivities to variations of hydrostatic parameters of soil.

Analysis of the thermal properties of soils

With financial support from the Canadian Industrial Development Agency, a team from Civil Research assisted the Egyptian Electrical Authority during 1983 in optimizing the design, installation and operation of underground power cables. The development and application of expertise in the analysis and specification of thermal backfills resulted in improved effectiveness of schemes for underground electrical systems in Cairo and Alexandria and led to a sizeable order for cable from Canada Wire and Cable Limited.

Subsequently, the team assisted Canada Wire and Cable by making extensive tests of the thermal properties of the native soils along the cable routes and of candidate backfill materials. This enabled the company to meet the specifications for design electrical loading.

A new way of monitoring hot spots in power transformers

Localized overheating is an important aspect of transformer loading because the paper insulation deteriorates rapidly at temperatures above 140°C. However, monitoring the highest temperature is not easy because the location of the hottest spot is usually unknown and measuring devices cannot be safely inserted inside a high voltage transformer.

One approach to the problem is to look for increasing quantities of dissolved carbon dioxide in the transformer oil as deteriorating overheated insulation produces large amounts of CO_2. Experiments have shown that a very simple infrared optical device can monitor the CO_2 content of transformer oil on a continuous basis. The technique has worked well on a small distribution transformer and will be tried on a larger power transformer.

Electronic recording ammeter

The traditional procedure for determining the loading on distribution circuits – installation of chart recorders out on the lines for a few days each year – involves problems related to cold-weather operation and to chart handling that make it a less than desirable process. However, an electronic recording ammeter (ERA) has been developed that provides significant improvement. The ERA uses microprocessor techniques, is battery powered, small and light, and can be mounted directly on the line with a live-line stick. It records average currents over 15-minute periods on lines up to 44 kV for up to three weeks. It is then removed, the data is transferred to a printer or storage, and the recorder is re-installed elsewhere. Further analysis of the data may be done by computer. The ERA has characteristics that make it suitable for wide application on the systems of Ontario Hydro and other utilities.

Automation of distribution systems

The general trend toward automation of distribution systems has stimulated research in two areas: analysis of propagation characteristics of the power line carrier (PLC) on distribution

systems; and evaluation of the overall automation concept through pilot installations on systems of municipal utilities in Ontario.

Remote control and the associated communication technology are the basis of system automation and load management. In the PLC project, mathematical system modelling is being developed which will enable prediction of communication channel performance. This will provide an important tool for assessing PLC capabilities and limitations.

Distribution automation and load management trial projects are being conducted at Scarborough PUC and Oshawa Hydro by the Distribution Systems and the Energy Conservation & Utilization Divisions. Participation of the Research Division includes theoretical analyses, and evaluation and development of special equipment, such as remotely controlled switchgear, compact voltage and current sensors, indicators of street lighting intensity, and storage-type domestic electric furnaces.

Metal-oxide arresters

Gapless arresters using disc-type metal-oxide valve elements have protective characteristics that are markedly better than those of the traditional gapped silicon-carbide arresters. Their use significantly reduces the insulation withstand requirements and thus the costs of electric power apparatus. During the past three years more than 200 gapless metal-oxide arresters have been installed on Ontario Hydro's transmission system at 115 kV, 230 kV and 345 kV.

Research directed towards application of this new technology is being done in co-operation with other Divisions. Field work on full-size arresters includes performance testing during switching operations and monitoring of peak resistive and total leakage currents and of the number and amplitude of current discharges. Laboratory work includes pulse testing of valve elements and monitoring of their thermal stability at elevated temperatures, vibration tests to assess stresses in shipping, and x-raying to assess structural integrity.

To analyze various applications of the metal-oxide arrester on distribution and subtransmission systems, digital models of distribution-class units have been developed. The models permit simulation of arrester response to various stresses caused by continuously applied voltage, switching or lightning surges and temporary 60-Hz overvoltages. The accuracy of these models is being verified by staging switching-surge, duty-cycle and temporary overvoltage tests on complete 18-kV and 21-kV arrester units.

Evaluation of polymer insulators

In cooperation with CEA, IEEE and the industry, distribution-class polymer insulators are being evaluated in the laboratory and the field for qualification as direct replacements for porcelain insulators in dead-end and mid-span line applications. The program includes evaluation of insulator design and material properties and analysis of the construction of weathershed components. The objective is development of a standard specification acceptable both to the electric utilities and to the industry.

Performance requirements now widely recognized include: high resistance to weathering and to damage from power arcs, gunfire, steep-front surges and vibration; adequate strength in torsion bending and tension at elevated temperatures; and easy removal of surface contaminants by live-line washing.

Elimination of PCB in transformer oils

An efficient, safe and economical method has been developed for removing polychlorinated biphenyls (PCB) from askarel-contaminated transformer oil. The process reacts liquid sodium with contaminated oil under controlled conditions to reduce PCB concentrations from as much as 60 000 mg/kg to less than 2 mg/kg in a two-hour period. The reaction is completely enclosed, the major by-product is common salt, and the recovered oil can be used again as dielectric fluid, thus conserving a valuable nonrenewable resource. A mobile PCB-removal plant has been designed and is expected to be ready for commissioning by mid-1984.

Pad-mounted transformer switching and protection fusing

A number of Canadian and U.S. utilities have reported violent failures of drywell canister fusing equipment in pad-mounted distribution transformers, some involving personal injury. In response, Ontario Hydro has been performing laboratory tests to establish the failure mechanism. Limited interrupting abilities of current-limiting fuses, component tracking and fuse gassing are some of the causes identified. Alternative, safer methods of overcurrent protection being considered for appraisal include under-oil fusing and an air-insulated dead-front fusing compartment.

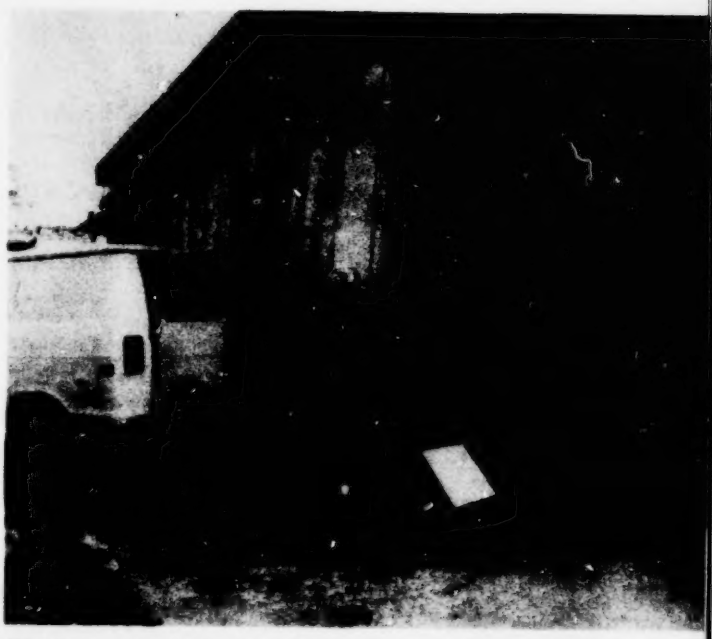
Energy Utilization and Conservation

New uses of electricity in industry

Growing requirements for lighter motor vehicles have increased demands by the auto industry for high-strength, low-alloy steels. These steels have not been produced in Canada because of the high cost of equipment required for heat-treatment. However, Ontario Hydro Research and a major steel producer have been investigating new methods of heat treating steel. One expected benefit of this co-operative effort is the development of less costly electrically powered heat-treating equipment that will make it economically feasible to produce the high-strength steels in Canada.

More than 25 per cent of all energy consumed by Ontario industries is used for product drying, and almost all of this energy is produced by burning fuels. However, substantial advantages in energy costs and process control can be gained through development of electrical techniques such as microwave and radio-frequency heating and heat pumping. For example, a heat-pump wood-dryer, installed by a furniture manufacturer to replace a steam heated kiln, reduced energy consumption by 60 per cent and improved wood quality.

A new laboratory to be used in further investigations of industrial utilization of electricity is scheduled for completion in the summer of 1984.



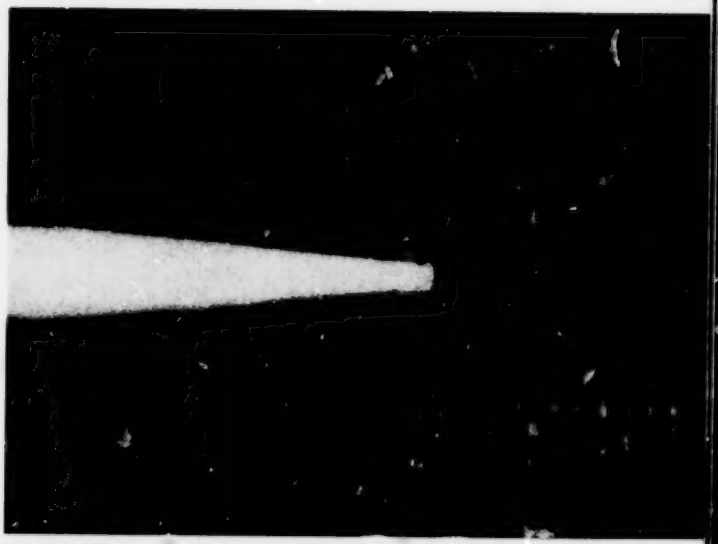
Wheeling in a data logger for monitoring a heat-pump wood-dryer installed by a furniture manufacturer.

Plasma research laboratory

The Research Division has established a laboratory to investigate industrial applications of thermal plasma technology.

Plasma torches, or electric-arc gas heaters, can heat gases to extremely high temperatures (close to 5000°C), and for this reason they are useful in chemical and processing applications that cannot be served by other forms of electric or combustion heating. Extraction metallurgy, chemical synthesis, heat treatment and metal fabrication are a few of the many potential applications. At present the laboratory has an 80-kW, dc, non-transferred-arc plasma torch with a particle injector to permit study of the behaviour of coal and metal-oxide powder in a plasma column. The torch is of modular design to accommodate a variety of gases for chemical synthesis studies, and there is diagnostic instrumentation for monitoring flame temperature and particle trajectories. A three-phase, ac torch with consumable electrodes is being installed and expansion of the laboratory to include a 1-MW test and demonstration facility is planned.

One of the main objectives of the laboratory is to foster closer cooperation between industrial users and Ontario Hydro in promoting plasma techniques and processes. Ontario Hydro is exploring the possibilities of participating in joint projects with companies in the steel, abrasive, glass and ceramic industries.



This 80-kW plasma torch, shown heating a stream of nitrogen gas, is part of the Division's thermal plasma research facility. Use of plasma-arc technology promises substantial benefits in industrial applications where high temperature, good energy economy, close process control and limited output of pollutants are important.

Energy Utilization and Conservation

Residential heat pumps for northern climates

A major research effort to boost the efficiency, reliability and cold-weather performance of heat pumps in the Ontario climate has led one of the province's manufacturers to build several prototype heat pumps to the Division's specifications. The work, sponsored by the CEA, is expected to culminate in the delivery of improved products to the marketplace. This could be of real benefit. Customers that use heat pumps rather than other forms of heating save on heating costs by as much as 40 to 50 per cent. Now heat pumps will be even more effective: it is estimated that customers will save a further $20 million over the next ten years if they choose units built to Ontario Hydro's specifications.

Work is continuing on the evaluation of heat pumps in people's homes throughout the province. Add-on heat pumps, water-source heat pumps, and ground-source heat pumps are all under scrutiny to provide Ontario Hydro and the Ministry of Energy with the information needed to develop energy conservation programs in the residential heating sector.

Dual-energy heating

Investigation of the technical and economic feasibility of adding electric heating to existing residential oil heating systems and the development and testing of equipment and procedures have been under way for five years. A specification for a 9-kW plenum heater (the U-9) with an outdoor temperature sensor was developed as a result of field trials with dual-energy heating systems. The unit's control automatically switches the heating system to oil firing during cold periods near the time of the annual system peak. Both the heater capacity and the control strategy were selected on the basis of data from field and laboratory tests to minimize costs to customers for installation and to utilities for supply electricity to dual-energy systems.

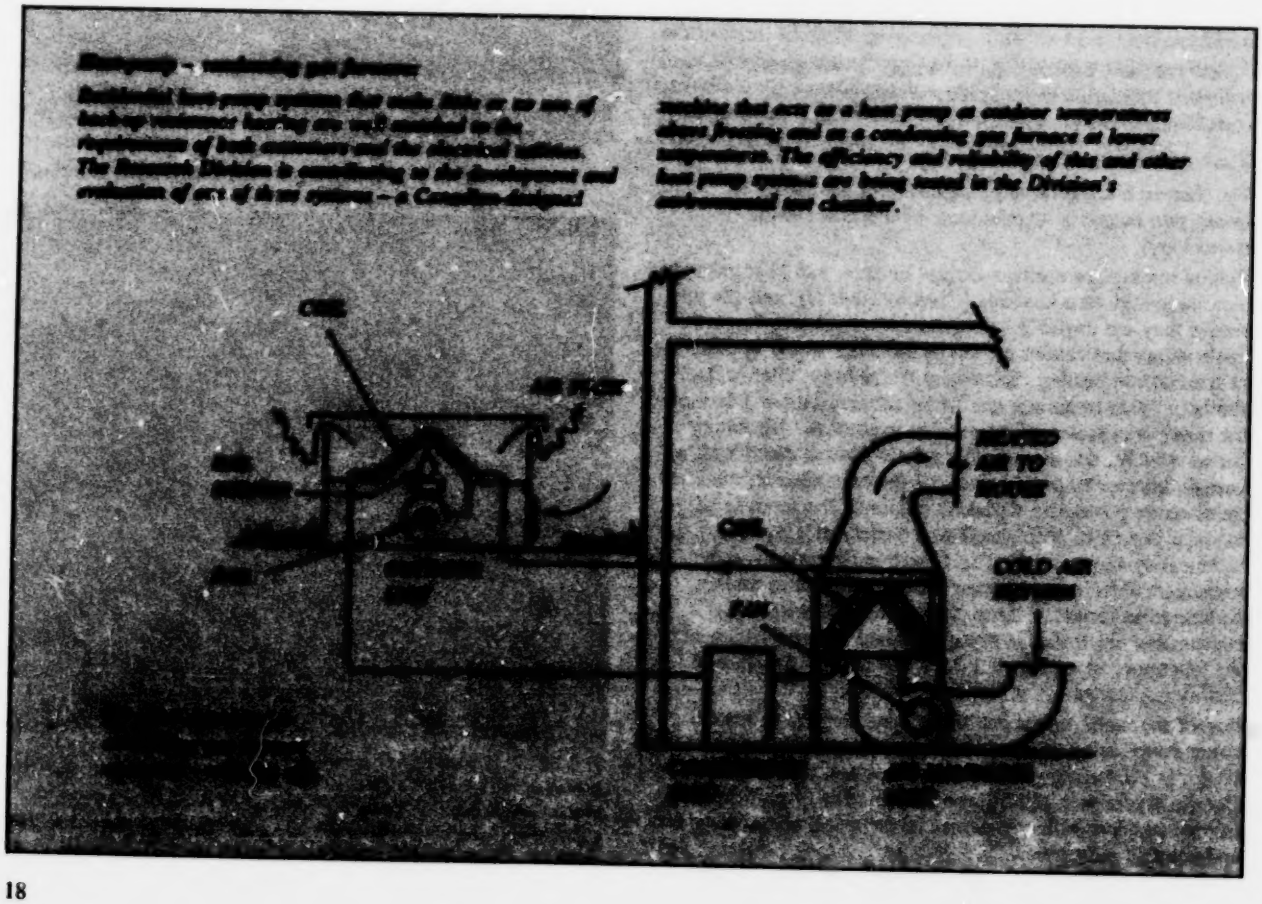
Other innovative devices and installation techniques, such as thermostat diode encoders, load shedders and new service entrance upgrading methods, were developed to allow dual-energy heating to be retrofitted to as many homes as possible in the province.

Ontario Hydro and the CEA co-operated in organizing the

Residential service-entrance tests

Extensive testing has been performed on service entrance equipment to ensure equipment safety and reliability are maintained when electric heating is added to a residence.

The results of accelerated aging tests performed on 60-A fusible switches indicated that switches manufactured before



1970 should be replaced when electric heating is added. Further testing, however, demonstrated the effectiveness of commercially-available fuse-clip clamping devices in improving the reliability of older switches.

Similar tests are now being performed on 60-A breakers to determine whether breakers are more suitable than switches as replacements. As well, plans are being made to test 100-A fusible switches and circuit breakers.

Effects of thermal upgrading of houses

Upgrading of the service entrance is a usual requirement of conversion to all-electric heating. However, if thermal upgrading of the building envelope could reliably reduce the required furnace size to fit the existing service, the costs for service-entrance upgrading could be traded-off for insulation costs which give continuing energy savings. A field project was undertaken in sixteen homes located throughout Ontario to determine accurately the reductions that can be achieved by various retrofitted energy conservation measures. These included improvement of air sealing throughout the structure (performed by both homeowner and contractor), and addition of insulation in the basement and attic. Preliminary findings show reductions in required furnace capacity of as much as 30 per cent.

Refinement of residential heat-loss calculations

Research Division measurements have shown that traditional heat-loss calculations lead to installation of heating systems that are twice as large as necessary on the average, and this has a strong adverse effect on the cost of all-electric conversions. However, the results of research on air infiltration rates, basement heat losses, and transmission heat losses through walls and ceilings have been applied in a revised Ontario Electric League heat-loss calculation which provides heating system capacity requirements that are more accurate, smaller and less costly, and less likely to cause comfort problems.

Heat recovery and water heating

The need to maintain acceptable air quality and humidity levels in modern, tightly constructed houses has led to development and use of systems that induce controlled air flows. Energy economy requires use of heat pumps to extract heat from exhaust air during the colder months and perhaps from in-drawn air during the summer. Depending upon availability and requirements, the extracted heat may be returned to the living-space air or used for heating water. Some water heating systems extract heat also from bathtub, kitchen and laundry drainwater.

Systems of this kind are being tested and assessed for performance and reliability by the Research Division. This work is near the forefront of a new field and is being done under contract or in association with several Canadian and American organizations that have related interests.

Ontario Hydro made a large contribution in the preparation of CSA Standard C191-M1983 "Performance of Electric Storage Tank Water Heaters". A new testing facility was set up in 1983 to permit side-by-side comparison of electric and natural gas water heaters. Comparative operating costs for these two water heating systems have been developed in support of marketing programs.

The technician is adjusting power supply for accelerated aging tests of 60-A service-entrance switches and circuit-breakers.

Nuclear Waste

In the program for management of irradiated nuclear fuel, Ontario Hydro is responsible for development of systems for interim storage and transportation, and AECL for development of systems for immobilization and ultimate disposal. Ontario Hydro continued to participate in its assigned part of this program in 1983, and undertook also design, welding, remote inspection and corrosion studies for containers to be used in ultimate disposal.

Reactor operating wastes

Baled solid wastes form the largest part of low- to intermediate-level radioactive wastes from reactor operation. These materials are being examined to determine the typical radionuclide composition and activity levels and to assess the potential hazards associated with their disposal.

Studies of materials and processes for the solidification of aqueous and organic tritiated wastes have shown that the preferred solidification and encapsulation agent is water-extended polyester, which has extremely low tritium-release rates when in contact with water. Work is continuing on the development of a mobile processing plant which is to be commissioned in 1984.

Transportation of irradiated nuclear fuel

As part of the development of a transportation system for waste nuclear-fuel, irradiated fuel-bundles from the Pickering and Bruce Generating Stations were evaluated in AECL's Whiteshell Nuclear Research Establishment. New fuel bundles with simulated hydriding were tested by the Research Division to determine the vibration and shock-loading levels that they can withstand. Vibration and shock-loads that might be expected during transportation were determined both analytically and experimentally. Shaker-table and impact testing of a fully loaded transportation module was performed and the results indicated that the irradiated fuel bundles would remain intact during transportation. This would facilitate the handling of the spent fuel by automated equipment.

Integrated containers for storage, transportation and disposal of nuclear wastes

Metal containers are being developed to allow highly radioactive materials to be isolated from the environment as is required by various codes and guides. The work involves the evaluation of several types of containers. The selected design will be used for the storage, transportation and disposal of materials that include irradiated fuel bundles, solidified reprocessed fuel, reactor components and high-level decommissioning waste.

A reinforced concrete cask is being developed as a possible alternative to the metal container. This also would have the integrated function of containing irradiated fuel in all phases of nuclear waste management.

A particulate-packed, thin-walled titanium container is also being developed for the long-term isolation of irradiated fuel bundles. Several particulates have been tested at ambient and elevated temperatures to establish their short- and long-term structural properties. A full-size prototype container has been built and tested to demonstrate feasibility of manufacture and suitability for the application.

The technician is introducing a pressure membrane to the required depth for measuring rock modulus and stress with an automated borehole dilatometer. The information will be used in accessing the effects of excavation on the rock mass at AECL's Underground Research Laboratory at Lac du Bonnet, Manitoba.

Development of evaluation of techniques and materials for long-term underground isolation

The Research Division has conducted borehole modulus and air vacuum tests in boreholes made in the granitic pluton at Lac du Bonnet, Manitoba. The purpose of this work was to determine if any rock damage occurred in the walls of the blast-excavated shaft which will form the entrance to the proposed underground high-level-waste-storage research laboratory. Detection and repair are important since fractures could provide pathways along which radionuclides could migrate to the surface.

Several clay-type buffer materials which are potentially suitable for emplacement around radioactive waste canisters are being assessed for heat dissipation, permeability, ion-exchange capacity, strength and deformability. The buffer material will reduce the aggressive attack of corrosive groundwater on the canister and minimize the possibility of escape radionuclides from the canister. Backfill materials, similar in nature to buffer materials, are being studied to ascertain their suitability as cavern and shaft backfills which will further isolate the waste canisters in the repository.

Clay-type and cementitious grouting materials, and installation techniques and equipment for use in sealing drill holes and access shafts are being investigated. These materials will be used to provide the final seal for the nuclear waste repository.

The Atmospheric Section of Chemical Research uses a van equipped with LIDAR (Light Detection and Ranging), a Doppler acoustic sounder and an instrumented helicopter in measuring the opacity, shape and chemical composition of stack-gas plumes at coal-fired generating stations.

Environmental Protection

Atmospheric physics and chemistry

A variety of studies in atmospheric physics and chemistry were carried out in support of Ontario Hydro's environmental protection program. Meteorological data and SO_2 concentrations were measured in the vicinity of the coal-fired Lakeview GS to provide a basis for operation of the intermittent emission control program at this station.

Results of dispersion studies at the coal-fired Nanticoke GS were analyzed and procedures were developed for prediction of emission behaviour at this plant. A method for use of LIDAR (Light Detection and Ranging) in measuring the opacity of smoke plumes was investigated, and work was begun on development of a model to describe the fate of trace elements and particulate emissions.

Transport and deposition of acidic atmospheric pollutant

In 1983 studies of acidic precipitation were focussed on poorly-understood processes such as dry deposition and cloud-pollutant interactions, and on modelling of long-range transport. An instrument package was assembled and used for the first time to measure the dry deposition of acidic gases. The first phase of a study of cloud-pollutant interactions in cooperation with the University of Toronto has provided a framework for modelling the role of clouds in converting, redistributing and depositing atmospheric pollutants. This analysis should improve our understanding of the factors that influence acid deposition – eg, atmospheric conditions and sources of emissions. A model of long-range atmospheric transport was adapted for use in estimating the contribution of our emissions to acid deposition.

Analysis of leachates from a model terrestrial system receiving synthetic acid rain did not demonstrate microbial utilization of sulphate and nitrate present in the rain. However, soil buffering against rainfall acidity was apparent.

Nuclear safety and environment

Research into the behaviour of radioactive emissions in the environment and the protection of workers against toxic substances, such as hydrogen-sulphide gas, continued in 1983. A meteorological survey was carried out at Pickering GS to determine the frequency of occurrence of unusual dispersion conditions. Preliminary plans were prepared for experiments under these conditions to test available dispersion models. Two such models were programmed for computers and used to help plan the 1983 Pickering Contingency Exercise. Studies of the behaviour of tritium in the atmosphere were continued and field tests of the rate of removal at the air-soil interface were carried out. This work will increase the reliability of Ontario Hydro's procedures for ensuring the safety of its nuclear facilities.

Environmental Protection

Tritium uptake by terrestrial and aquatic organisms

A program is under way to model the behaviour of emissions of tritium from CANDU reactors in terrestrial and aquatic environments. These emissions consist of tritiated water, the predominant form, and small quantities of elemental and organic tritium. Investigations to date have focussed on measurement of tritiated-water uptake and desorption kinetics in representative terrestrial and aquatic organisms. These include tomatoes, and algae, crayfish and fish that constitute a simulated aquatic food-chain.

Calculations of the tritium specific activity relationships between tritium source (air, water and food) and the test organisms showed that tritium does not accumulate in either the tissue-water or the organic components of the test organisms, thereby supporting the assumptions of the commonly employed tritium specific activity model. Reports in the literature on environmental samples had indicated concern for elevated tritium activity in organic constituents of organisms relative to either source tritium or tissue-water tritium. The results will provide a more reliable and complete data base from which derived emission limits and dose to man may be calculated.

Impacts of thermal and nuclear plant on the aquatic environment

Studies of the impacts of the construction and operation of Ontario Hydro nuclear and fossil-fuelled generating stations on the aquatic environment are carried out at new generating facilities. These studies compare data collected for three years in advance of station-operation with post-operational data collected for three years after commissioning of all units to determine whether changes have occurred in the aquatic environment as a result of station operation. The scope of the studies includes physical-chemical parameters, such as water and sediment chemistry, temperature regimes and sedimentation, as well as the characteristics of the biotic communities, such as phytoplankton, zooplankton, macroinvertebrates, attached algae, and larval, juvenile and adult fish. In 1983 studies were carried out at Pickering GS 'B', Bruce GS 'B' and Atikokan GS.

Reduction of fish impingement at generating station intakes

Work continued on the development of cost-effective means for stopping fish from entering generating station cooling-water intakes and for returning those that do enter to the lake or river with minimal adverse effects on the fish and on operation of the station. Behavioural systems that use lights, poppers and air bubbles to discourage fish from entering the intakes were developed and tested successfully both independently and in cooperation with American utilities. A new, flat, slotted intake, designed to reduce fish capture, was developed for Darlington GS.

Vegetation control on transmission line rights of way

Studies of the effects of the time, frequency and type of vegetation treatment along transmission line rights of way are expected to lead to improvement of vegetation control and reduction of undesirable environmental impact.

For herbicides to be effective agents of vegetation control, sufficient herbicide must reach the roots and lower stem of woody plants to prevent subsequent sprouting and suckering. At the tree nursery at Wesleyville GS, sprouting and suckering on cut stumps of basswood, white ash and silver maple are being monitored as functions of time of year at which the cutting was done and of the application of herbicide to the cut stump.

Cover crops are planted by Ontario Hydro to prevent soil erosion and to inhibit the invasion of the right-of-way by undesirable woody species. Eighteen cover crops have been screened in the laboratory for effectiveness in inhibiting the development of some woody plants. Several species of cover crop, legumes for example, were found to be particularly effective and investigations of the inhibitory mechanisms of these crops were begun.

General Research

Analysis of wear particles by ferrography

Ferrography, an analytical technique used for examination of wear particles in a sample of lubricant, allows the in-situ condition of inaccessible mechanisms to be monitored. The technique has been developed to separate wear debris from the lubricant and arrange it according to size on a transparent substrate for examination under optical or scanning electron microscopes. The particles are analyzed in relation to wear mode, severity of wear and origin of wear material in order to diagnose the condition of components and thus predict impending machine failures. This permits timely maintenance to prevent failure.

Ferrography is proposed as a machinery-health monitoring technique to be developed in Canadian electrical utilities for use on equipment that is of critical importance in the production of power. Possible applications include turbine-generators, pulverizers, boiler feed pumps, holding pumps, circulating water pumps, heat transport condensate pumps, internal combustion engines, and diesel and gas engines. The technique has been applied successfully in other industries.

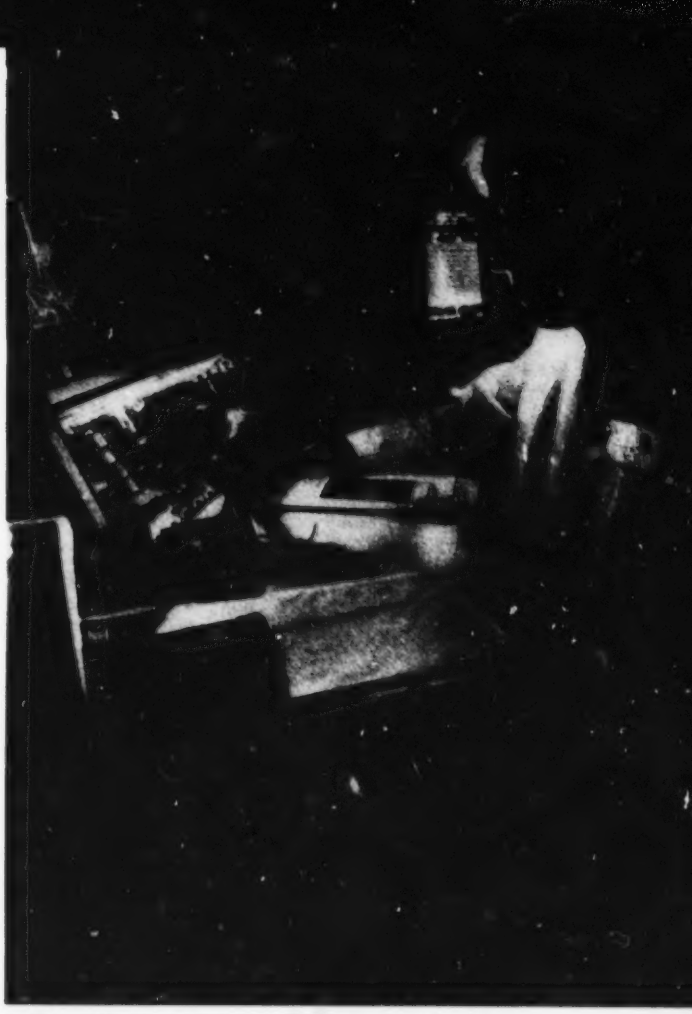
Conservation of energy, materials and equipment

Under contract with the Federal Department of Energy, Mines and Resources, the Research Division has undertaken to determine the potential effect on the Canadian economy of losses in energy, materials and equipment that result from friction and wear of surfaces in relative movement. Similar studies done in the UK and the USA have been adapted to allow for Canadian conditions, and this has indicated that appropriate applications of research and developments in tribology – the study of moving surfaces, friction, wear, lubrication and related effects – could reduce losses of this kind in Canada by an amount in the range from $500 million to $2 billion annually.

The study will attempt to confirm and refine this estimate through surveys of industries in various sectors of the economy and through identification of components, equipment and processes responsible for major tribological losses, and thus initiate a strategy for tribological research and development in Canada.

Fall protection for linemen

In co-operation with the Transmission Systems Division a comprehensive fall protection system has been developed for linemen erecting transmission lines. For the first time in North America, linemen will be protected against falling at all stages of transmission line construction, including tower erection, insulator hanging, clamping-in and spacer-damper installation. The project included development or selection of the equipment, development of fall-arrest systems, modification of construction methods, field trials, and full lineman training. Linemen in each of Ontario Hydro's three Construction Zones now use the developed systems in their everyday work.



This scanning electron microscope, equipped with an X-ray analyzer, provides elemental composition analysis and high-resolution imaging for metallographic, biological and geological studies.

Organic materials research

Work continued on the qualification and performance testing of the wide range of organic materials used by Ontario Hydro on its power system.

Typical activities are failure analysis, and prediction of performance and service life for materials affected by severe conditions of ionizing radiation, heat, water immersion, vacuum and corrosion. Techniques for accelerated aging have been developed to provide data for prediction of the electrical and mechanical properties of cables after 40 years of service.

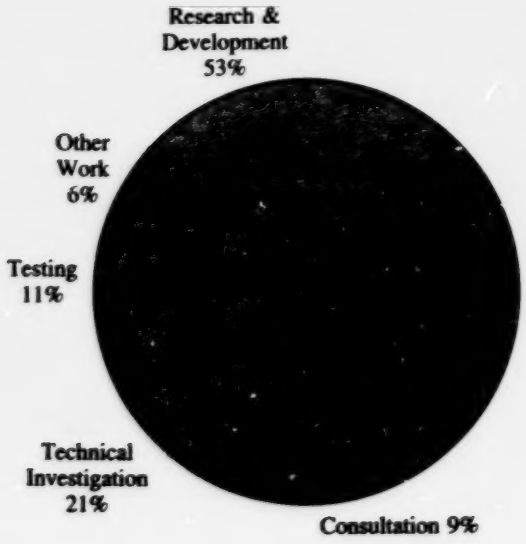
A two-storey burn-hall permits full-scale investigation of the combustion properties of materials and equipment such as plastics, power and control cables, electrical machinery and office furniture. The burn-hall is used in studies of fire hazards, fire precautions and the initiation and development of combustion, and in evaluations of fire and flame retardants, fire and smoke detectors, and fire extinguishing systems. A scrubber keeps smoke and other effluents within regulatory limits.

Resources and Costs

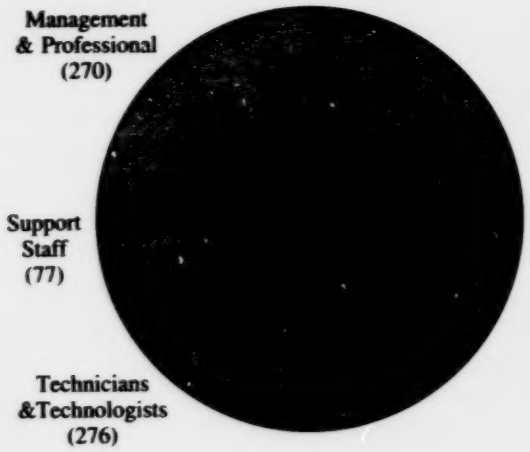
The Research Division's resources of plant and equipment are shown and described in the outline on page 3. At the end of 1983, the Division's personnel resources consisted of a total regular staff of 623. The administration and organization of staff are shown on the opposite page. The distribution of staff in broad occupational classes is shown at the right, and its application in various categories of work (Divisional Services Department excepted) is shown below.

Proportions of total salary cost for various categories of work:

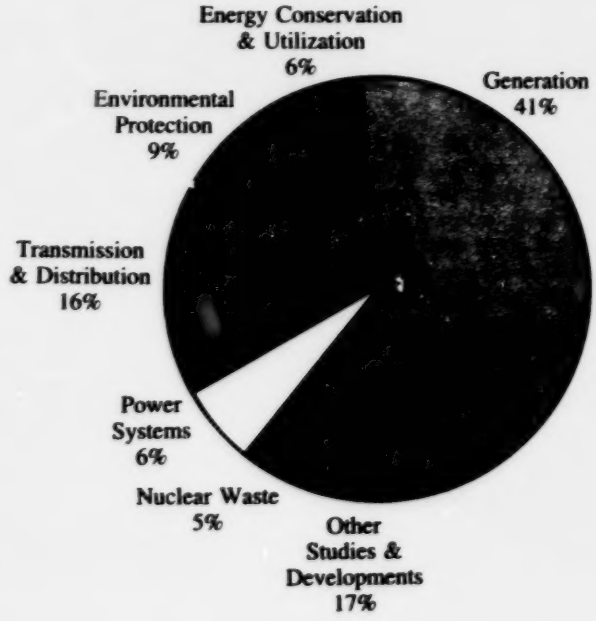
- Testing – performed to prove the value or determine the nature of something;
- Consultation – provision of advice or information to aid in making decisions;
- Technical Investigation – application of scientific or engineering principles to solving non-routine problems that do not require new knowledge or materials;
- Research – original investigation in some field undertaken to establish facts or principles;
- and Development – application of research discoveries and other scientific knowledge toward improvement of products and processes as required to meet current and expected needs of Ontario Hydro.



Occupational classification of Research Division staff



Proportions of gross costs for major areas of research.



The total of all costs, including those for space, material and equipment, for work done by the Research Division in 1983 was approximately $42.9 M.

Costs were met or allocated as follows:

Revenue from work done for other organizations	$ 2.8 M
Transfers to other Ontario Hydro Branches	16.6 M
Transfers to the Cost of Power	23.5 M

DIRECTOR OF RESEARCH F.J. (Fred) Kee

ELECTRICAL A.F. (Anton) Baljet

MECHANICAL G.J. (Gord) Clarke

METALLURGICAL O.A. (Al) Kupcis

CHEMICAL D. (Doug) Harrison

CIVIL T.W. (Tony) Klym

OPERATIONS RESEARCH J.G. (Jack) Cassan*

DIVISIONAL SERVICES J.B. (Bruce) Brown

DIVISIONAL PROJECTS J.G. (Jack) Cassan

Publications and Presentations

Publications

American Society of Mechanical Engineers

Journal of Solar Energy Engineering, Vol. 105, No. 3, August 1983, pp 246-53

"A Numerical Study of Transient Mixed Convection Flows in a Thermal Storage Tank" *A.M.C. Chan, P.S. Smereka* and *D. Giusti*

Atomic Energy of Canada Limited Technical Record TR-225

"Vacuum Permeability Testing" *A.T. Jakubick*

Canadian Acoustics, Vol. 11, No. 2, April 1983, pp 25-36

"Noise Source Identification—Acoustic Intensity Technique" *J.J. Kowalewski*

Canadian Centre for Mineral & Energy Technology (CANMET)

A Report on Cooperative Mine Safety Research Program

"Transient Vacuum Testing Near-Field Permeability of Underground Openings" *A.T. Jakubick* and *R. Klein*

Canadian Metallurgical Quarterly, Vol. 22, No. 1, 1983

"The Corrosion Behaviour of Copper Under Simulated Nuclear Waste Repository Conditions" *P.J. King, K.W. Lam,* and *D.P. Dautovich* (Canadian Centre for Fusion Fuels Technology)

Canadian Meteorological and Oceanographical Society

Proceedings of Mesoscale Meteorology Workshop

"Applications of Mesoscale Modelling at Ontario Hydro" *A.C. McMillan* and *Y. Tam*

Operations Research Society of America

Operations Research Letters, Vol. 2, No. 4, November 1983, pp 165-69

"Performance of an Unscheduled Shuttle System with Two Classes of Vehicles" *S.H. Sim*

Optics Communications, Vol. 47, No. 1, pp 62-64

"Tunable Infrared Difference—Frequency Generation in Lithium Iodate" *L. Mannik* and *S.K. Brown*

Third International Conference on Numerical Methods in Thermal Problems

Proceedings, pp 718-28

"Numerical Simulation of Transient Turbulent Buoyant Flows" *A.K. Ahluwalia* and *M. Shoukri*

Water Research, Vol. 17, No. 12, pp 1847-53

"Effects of Temperature Elevation and Entrainment on Heterotrophic Uptake of 14C-U-Glutamic Acid" *T.G. Dunstall* and *C.J. Schwarz*

Presentations

Air Pollution Control Association/Pollution Control Association

April 1983, London, Ontario

"Utility Environmental Research in the 80's" *F.J. Kee*

American Ceramic Society

Cement Division Annual Meeting, April 1983, Chicago, Illinois

"Evaluation of Concrete Casks for the Management of Irradiation Fuel In Canada" *N.C. Burnett* (Design and Development Division) and *R.D. Hooton*

"Porcelain Insulator Failures from Cement Grout Expansion" *R.D. Hooton*

American Meteorological Society

Conference on Probability and Statistics, November 1983, Hot Springs, Arkansas

"Statistical Identification and Interpretation of Meteorological Scenarios for Local High SO_2 Levels" *T.J. Barker* and *A.C. McMillan*

American Nuclear Society

Topical Meeting on Technology of Fusion Energy, April 1983, Knoxville, Tennessee

"Tritium Monitoring Requirements of Fusion and Ontario Hydro Experience—A Comparison" *S.B. Nickerson, R.F. Gerdingh* (Monserco Ltd.), *K. Penfold* (Canatom Inc.) and *D.P. Dautovich* (Canadian Centre for Fusion Fuels Technology)

American Society of Mechanical Engineers

Conference on Pressure Vessel and Piping. Symposium on Temperature and Environmental Effects in Fatigue, Research—Design Interface June 1983, Portland, Oregon.

"Fatigue/Creep Crack Growth Characteristics of 2-1/4 Cr-1 Mo Steel in the Normalized and Tempered Condition" *H.J. Westwood* and *W.K. Lee, D. Sidey* (Thermal Generation Division), and *P.M. Sooley* and *D.W. Hoeppner* (both of the University of Toronto)

Winter Annual Meeting, Boston, Massachusetts, November 1983

"Numerical Simulation of Turbulent Mixed Connection Flows" *A.K. Ahluwalia* and *M. Shoukri*"

American Society for Nuclear Testing

Automated Nondestructive Testing, June 1983, Idaho Falls, Idaho

"Ultrasonic Assessment of the Quality of CANDU Reactor Fuel Channel Rolled Joints" *M.P. Dolbey*

American Society for Testing and Materials

Sixteenth National Symposium on Fracture Mechanics, August 1983, Columbus, Ohio

"Axial Fracture Toughness of Zr-2.5% Nb Pressure Tube Material" *P.H. Davies* and *C.P. Stearns*

"Effect of Hydrogen on Crack Initiation and Crack Growth in 18Mn-4Cr Steel" *Y.J. Kim, B. Mukherjee* and *D.W. Carpenter*

Association of Municipal Electric Utilities (Ontario)

Technical Workshop, April 1983, Toronto, Ontario

"Performance of the U-9 Plenum Heater in a Dual Energy System" *R.L. Hicks*

Canadian Electrical Association

Distribution Section Spring Meeting, March 1983, Vancouver, British Columbia

"Bias in Estimation of Reliability Indices due to Rounding of Reported Times" *C.E. Hughes*

Canadian Society for Chemical Engineering

33rd Chemical Engineering Conference, October 1983, Toronto, Ontario

"Corrosion Research Studies in a Power Utility" *J. Brown*

"Laser Isotope Separation—A New Class of Chemical Process" *K.B. Woodall, L. Mannik, J.A. O'Neill, D.L. Mader, S.B. Nickerson, J.R. Robins, F.E. Bartoszek,* and *D.G. Gratton* (Design and Development Division)

CIGRE (International Conference on Large High-Voltage Electric Systems)

Conference on Hydraulic Generators and Synchronous Compensators, November 1983, Rio de Janeiro, Brazil

"Diagnostic Testing of Generator Insulation Without Service Interruption—End Cap Coupler" *M. Kurtz* and *G.C. Stone*

Conference on Deformation of Multi-Phase and Particle-Containing Materials, September 1983, Riso National Laboratory, Roskilde, Denmark

"Deformation Behaviour of Zr-2.5 wt% Nb in the Temperature Range 723 to 1023K" *E.T.C. Ho* and *V. Perovic*

Edison Electric Institute

Annual Meeting, May 1983, Atlantic City, New Jersey

"Operating Experience with GIS—A Survey of Lessons Learned" *S.A. Boggs* and *F.Y. Chu*

Electric Power Research Institute

Assessment Workshop on Active Solar Research and Development, August 1983, Palo Alto, California

"Active Solar-Programs and Prospective" *M. Perlman*

Institute of Electrical and Electronics Engineers

Electrical-Electronics Insulation Conference, October 1983, Chicago, Illinois

"Experience with the CEA Generator Insulation Partial Discharge Test" *M. Kurtz, G.C. Stone,* and *J.F. Lyles* (Hydraulic Generation and Transmission Revision)

Conference on Pulsed Power, June 1983, Albuquerque, New Mexico

"Magnetic Metal Forming by Reversed Electromagnetic Forces" *M. Cenanovic*

Summer Power Meeting, July 1983, Los Angeles, California

"Five Years' Field Trials of Detuning Pendulums for Galloping Control" *D.G. Havard* and *J.C. Pohlman (Consultant)*

"Protection of Electronic Equipment from Substation Electromagnetic Interference" *S.M. Harvey*

"Uprating of Transmission Lines by Probability-Based Methods—A Case History" *S.G. Krishnasamy*

"Weather-Induced Transmission Line Loads on a Probabilistic Basis" *S.G. Krishnasamy*

Winter Power Meeting, January-February 1983, New York, New York

"Calculation of the Sensitivity of Power Cable Ampacity to Variations of Design and Environmental Parameters" *M.A. El-Kady*

"Cement Growth Failure of Porcelain Suspension Insulators" *E.A. Cherney*

"Computer-Aided Planning of Distribution Substation and Primary Feeders" *M.A. El-Kady*

"Lightning Surge Response of Transmission Towers" *W.A. Chisholm* and *P.G. Buchan*

"Lightning Surge Response of Transmission Towers" *W.A. Chisholm, Y.L. Chow* (University of Waterloo) and *K.D. Srivastava* (University of Waterloo)

"The Ontario Hydro Process for Dechlorination of PCB-Contaminated Insulating Fluids" *W.J. Janis, J.S. Ferrie* and *J.M. Braun*

"Reliability of Epoxy Components in High-Voltage Switchgear" *G.C. Stone, S.A. Boggs, J.M. Braun* and *M. Kurtz*

"Reliability Modelling of Thermal Units for Peaking and Cycling Operations" *L. Wang, N. Ramani,* and *T.C. Davies* (Thermal Generation Division)

"Risk Assessment of Grounding Hazards Due to Step and Touch Potentials Near Transmission Line Structures" *M.A. El-Kady* and *M. Vainberg*

International Conference on Heat Transfer, September 1983, Munich, West Germany

"Effect of Natural Convection on Freezing in a Cavity" *A.M.C. Chan, M. Shoukri,* and *P. Smereka (University of Waterloo)*

"An Experimental Investigation of Two-Phase Flow Interactions in Horizontal Rod Bundle Geometrics" *M. Shoukri, H. Tawfik* and *W.I. Midvidy* (Design and Development Division)

"Void Waves, Oscillations and Flow Regimes in Horizontal Flow Boiling" *A.M.C. Chan, B.A. Piggot* (Design and Development Division) and *S. Banerjee* (University of California)

International Conference on Phenomena in Ionized Gases, July 1983, Dusseldorf, West Germany

"Impulse Breakdown of a Rod-Rod Gap in SF_6 Shielded With Parallel Insulating Barriers" *F. Lutz* (Sachsenwerk) and *F.Y. Chu*

Publications and Presentations

International Conference on Numerical Methods in Nuclear Engineering, September 1983, Montreal, Quebec

American Nuclear Society and Canadian Nuclear Society

"Numerical Simulation of Two-Phase Flow in Horizontal Interconnected Subchannels" *M. Shoukri* and *A. Tahir* and *M.B. Carver* (both of Atomic Energy of Canada)

International Conference on Reliability-Availability-Maintainability, May 1983, Montreal, Quebec

"Models for Predicting the Reliability Performance of Standby Systems in Generating Stations" *S.H. Sim* and *M.S. Grover* (Design and Development Division)

International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, July-August 1983, Montebello, Quebec

"Durability of Fly Ash Concrete" *V.R. Sturrup, R.D. Hooton* and *T.G. Clendenning*

International Conference on Wind Engineering, March 1983, Gold Coast, Australia

"Weather-Induced Loads on Overhead Transmission Conductors" *S. Krishnasamy*

International Symposium on Dual Fuel Heating, October 1983, Toronto, Ontario

"Dual Energy Heating—A Summary of Ontario Hydro's Field Experiment" *F.G. Pellini*

"Electrical Service Entrance Designs for Dual Energy Heating" *C.E. Keyes*

"Residential Heating Equipment Capacity Calculation" *W.R. Jones*

"Three Years of Measured Performance for Two Dealer-Installed Add-On Heat Pumps" *D.J. Young*

International Symposium on Field Measurements in Geomechanics, September 1983, Zurich, Switzerland

"Vacuum Logging for Measurement of the Integrity of the Near-Excavation Zone" *A.T. Jakubick*

International Symposium on Packaging and Transportation of Radioactive Materials, May 1983, New Orleans, Louisiana

"Integrated Metal Container as a Part of an Integrated System for Back-End of Irradiated Fuel Management" *B. Teper* and *B.R. Reynolds* (Design and Development Division)

"Thermal Analysis for the Design of a CANDU Irradiated Fuel Transportation Cask" *D. Taralis* and *K.E. Nash* (Design and Development Division)

International Symposium on Plasma Chemistry, July 1983, Montreal, Quebec

"Design and Laboratory Utilization of a Thermal Plasma Generator" *G.N. Liu* (Acurex Corporation), *F.Y. Chu* and *C.J. Simpson*

"SF_6 Decomposition in a Plasma Arc for Various Electrode Materials" *F.Y. Chu* and *F. Lutz* (Saschsenwerk)

International Symposium on Soil and Rock Investigations by In-Situ Testing, May 1983, Paris, France

"Bedrock Degradation as Determined from Plate Bearing Tests" *R. Koopmans*

Ontario Secondary School Teachers Advisory Council, June 1983, Ontario Hydro Conference and Development Centre, Orangeville, Ontario

"Energy Education" *F.J. Kee*

Second Australian Coal Preparation Conference, October 1983, Rockhampton, Australia

"Coal Cleaning by Oil Agglomeration with Oil Recovery" *Y.V. Nguyen, R.W. Glass,* and *R.W. Row* (Electric Power Research Institute)

Second International Topical Meeting on Nuclear Reactor Thermal Hydraulics, January 1983, Santa Barbara, California

American Nuclear Society, American Society of Mechanical Engineers and American Institute of Chemical Engineers

"Two-Phase Redistribution in Horizontal Subchannel Flow—Turbulent Mixing and Gravity Separation" *M. Shoukri, H. Tawfik* and *A.M.C. Chan*

Solar Energy Society of Canada

Annual Conference, August 1983, Windsor, Ontario

"Ground Source Heat Pumps" *F.J. Lenarduzzi*

Symposium on Thermal Utilities Boiler Reliability, May 1983, McMaster University, Hamilton, Ontario

"Residual Life of Boiler Tubing" *H.J. Westwood, M.D.C. Moles,* and *R.B. Dooley* and *D. Sidey* (both of the Thermal Generation Division)

Welding Institute of Canada

International Conference on Welding in Energy Related Projects, September 1983, Toronto, Ontario

"Welding 304L Stainless Steel Tubing Having Variable Penetration Characteristics" *M.J. Tinkler, I. Grant* and *G. Mizuno* (both of Atomic Energy of Canada) and *C. Gluck* (Generation Projects Division)